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An evaluation of certain agronomic and disease characters in advanced generations of bulk hybrid oat populations

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AN EVALUATION OF CERTAIN AGRONOMIC AND DISEASE CHARACTERS IN ADVANCED GENERATIONS OF BULK HYBRID OAT POPULATIONS

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INTRODUCTION

The breeding of improved varieties of cereal crops has become more complex both from an agronomic and pathological viewpoint. In the early stages of improvement it was possible to make rapid progress in obtaining improved types utilizing a pure line selection procedure with the available germ plasm. The earlier plant breeders were successful in developing higher yielding, more disease resistant varieties. The widespread use of these varieties was an important step in bringing to the attention of farmers the potential value of crop improvement. In later years plant breeders have utilized this germ plasm from the previous selection program and through extensive hybridization and subsequent selection produced varieties of a still higher level of acceptability. The distribution of such high yielding disease resistant types in oats has changed, to a considerable degree, the conception of the value and place of the oat crop in a general farming program. While oats are still considered a valuable companion and rotation crop, they have become of increased importance as a cash crop. Many farmers make fertilizer applications and take greater care in selecting and treating seed to obtain maximum yields.

Because yielding ability of present oat varieties may be approaching the upper limit attainable, and because disease problems are continually becoming more complex through the production of new forms or physiologic races of the pathogen, it would appear that improvement of the crop in the future will become increasingly difficult. To meet these problems, breeding practices should then be of a type that will enable the plant breeder to observe large numbers of crosses and to evaluate the potential value of these crosses as quickly as possible. Crosses of little potential value can then be discarded and greater efforts concentrated on the more promising combinations.

Most small grain breeders at present use either the pedigree or the bulk method of breeding, or other modified systems or combinations of systems. The bulk method has the advantage of enabling the investigator to observe a greater amount of germ plasm in the early segregating generations and to obtain information on the yielding ability of the bulk material in replicated trials. It is assumed in this system that crosses which produce the highest yields in early generation bulk trials will in turn produce the highest yielding selections when pure lines are made from this material in later generations. Small grain breeders are not in agreement, however, as to the validity of this assumption. Investigations in the various crops have produced rather conflicting conclusions as to the value of the bulk method. Experiments pertaining to various phases of the problem have been conducted with barley, wheat and soybeans, but critical evidence on the value of the bulk method in oat breeding is not available. The investigations reported in this study were conducted in an attempt to obtain information on certain phases of the problem as related to the breeding of improved oat varieties. These results also may be of value and applicable to other small grain crops.

REVIEW OF PERTINENT LITERATURE

The work of previous investigators both with self- and cross-fertilized species pertinent to the problems encountered in the use of the bulk hybrid method in soybean investigations has been rather extensively reviewed by Kalton (16). Literature considered in this review will, therefore, be limited primarily to investigations applicable to the use of the bulk method in breeding small grains and to such other literature as may have bearing on the disease and natural selection aspects of this study.

Hayes and Immer (11) have classified the methods of breeding self-pollinated crops through the use of hybridization into four categories, namely, the pedigree method, the bulk method, the backcross method, and the use of multiple crosses. Among small grain breeders the pedigree and bulk methods have been most widely used, though the backcross method also is of considerable value in many breeding programs. The bulk and pedigree methods are compared and contrasted by Hayes and Immer (11) and by Love (22). The pedigree method consists of growing the hybrid material in space planted rows beginning with the F_2 generation and keeping a system of records to trace individuals from one generation to the next. Selection of desirable types with regard to various agronomic and disease characters is practiced both on a progeny and individual plant basis until the F_5 or F_6 generation. Homozygous lines are then bulked and tested for yield and other characters. The bulk method consists of growing the hybrid material in a bulk plot from the F_2 to about the F_5 or F_6 generation. This system provides ample seed for conducting replicated yield tests of the bulk material during this period, but permits only the forces of natural selection to act upon the segregating population. Individual heads or panicles are selected from the bulk material in F_5 or F_6 and evaluated in plant rows for disease reaction and agronomic characters. Desirable types are then further increased and tested in replicated trials for yield and other agronomic characters.

The bulk method is considered to have the advantage of requiring less detailed record keeping and of allowing larger populations of a greater number of crosses to be grown during the segregating generations. The investigator also is able to obtain yield data on replicated tests during the early segregating generations. The disadvantages of the bulk method are that it does not lend itself to individual plant and genetic studies, and that it requires a slightly longer time to carry through than the pedigree system. Without selection prior to the F_6 generation it is necessary to evaluate a larger number of plants in progeny rows than is necessary with the pedigree method where lines may be discarded as early as in the F_3 generation.

A modification of the bulk method, called the mass-pedigree method, has been suggested by Harrington (9). This method is a combination of the bulk and pedigree methods. Crosses are grown in bulk until seasonal conditions particularly favorable for selection are encountered. Selections are then made and their progeny tested in subsequent generations. A wet season or a combination of long straw and high winds were cited as providing excellent opportunity for selection for resistance to lodging, or a satisfactory disease epiphytotic may occur naturally and provide opportunity for selection of resistant plants.

Investigations on the use of the bulk method in small grain breeding programs have been conducted with barley and wheat with varying degrees of success reported for this system. In a study of six barley crosses Immer (14) grew the bulk F_2, F_3, and F_4 generations in replicated yield trials to determine their breeding value. The two crosses that produced the highest yields in F_2 and F_3 were found also to be among the highest in F_4, while two crosses were found to be relatively low in all generations tested. It was concluded that such yield trials may be used to discard certain crosses since the proportion of high-yielding genotypes in the low-yielding crosses would be less than in crosses with a higher average yield. The use of the F_1 generation to determine the average yields in later generations was cited as being seriously limited. The small amount of available seed would require space planting. Yield performance in space-planted rows was shown to differ greatly from performance of the same crosses in drilled rows.

Results of studies of 379 barley crosses made from twenty-eight parent varieties selected from all over the world were reported by Harlan, Martini and Stevens (7). The crosses were carried as pedigree crosses in separate rows for seven generations and bulk seed of each cross simultaneously tested for yield in a single ten-foot row. Selections were made from each cross in the eighth generation in proportion to their yield performance in the bulk rows. The yields of the pedigree crosses before selections were made were found to be a sound indication of the crosses from which high yielding segregates might be expected. It was concluded that the low yielding crosses could have been discarded without loss on the basis of their pre-selection yields. Seed of the 379 crosses also was mixed in equal amounts in the F_2 generation and grown in a field plot as a composite mixture through the seventh generation. Selections were made from the composite mixture in the eighth generation and selections obtained in this manner were found to compare favorably with selections obtained by the method of pedigree cultures.

Harrington (10) conducted replicated half-rod row yield trials with bulk unselected seed of ten wheat crosses in F_2 and with six crosses in F_3. The yielding value of the latter six crosses was determined later by replicated rod row yield tests of selected lines in F_6, F_7, and F_8. Harrington concluded that replicated bulk F_2 tests could be used to indicate the yielding potentialities of wheat crosses, and that bulk F_3 tests had supplementary value in this regard. It was pointed out, however, that for such characters as milling and baking quality, disease resistance and resistance to certain weather conditions the bulk hybrid trials may be of little value.

Nineteen wheat crosses were handled by the bulk-population method in an experiment conducted by Florell (3). Selections were made from nine of the crosses in F_5 and from ten crosses in F_6 and later grown in replicated rod row plots. The average yields of thirty-three of the forty-five selections grown in the replicated yield test, or 73.3 per cent of the total number, were found to be above the average yield of all check rows. The bulk method was found to be adapted for the development of strains possessing such characters as winterhardiness, rust resistance, and smut resistance. The number of generations required before selection was believed to depend on the number of character differences involved, and seven or eight generations was generally considered sufficient.

Weiss, Weber and Kalton (29) conducted investigations on the value of early generation testing in a soybean breeding program. Seventeen crosses were studied using both the pedigree and bulk methods of breeding. They state that bulk population tests gave reasonably accurate evaluation of crosses for lodging resistance and height of subsequent selections. For prediction of potential yield or date of maturity the bulk method was found to be of little value.

Investigations which do not directly involve the use of bulk-population yield trials in early segregating generations, but approach the problem of predicting the value of different crosses from data obtained in the F_2 generation have been conducted by Harrington (8) and by Immer (15). Harrington reported the results of extensive breeding work with the wheat cross Marquillo x Marquis as compared with his original expectation and the expectation calculated from a study of random F_2 populations. He grew an F_2 population of nearly 40,000 plants to assure a good chance of achieving the desired genotype. After five years of breeding effort only six lines remained and none of these was found to be entirely satisfactory. The analysis of random F_2 populations for various important agronomic characters and stem rust reaction had indicated that about seven good lines could be expected from the population. It was concluded that the F_2 analysis gave a reasonably accurate prediction of the value of a cross, and that a preliminary experimental F_2 population of several hundred plants should be analyzed for all important characters before the beginning of extensive work on a cross. It was pointed out that such an analysis would have distinct limitations with respect to characters such as baking quality, which could not be studied in F_2. Immer (15) investigated the use of means and variances of space planted F_2 material for predicting the yielding ability of barley crosses in subsequent generations. He concluded that the yield of an F_2 plant was determined very largely by factors of environment and would supply essentially no information on yield in later generations.

The effects of natural selection and competition are of paramount importance in any consideration of the value of the bulk hybrid method of breeding cereal crops. Harlan and Martini (6) studied the effects of natural selection on a mixture of eleven varieties of barley grown at ten stations for a period of four to twelve years. Population counts were made annually to determine the effects of selection pressure in the population as measured by the relative proportions of the surviving strains. It was found that at all locations there was a rapid elimination of the less adapted sorts and at most locations the variety that would eventually dominate the population was quickly evident. The population trends were found to agree in general with a series of theoretical curves. The poorest varieties were cited as showing the same type of descending curve at all locations, and the best variety exhibited a typical ascending curve, which for a time approached a straight line.

Suneson and Wiebe (27) grew mixtures of different varieties of barley and different varieties of wheat in 1/50-acre plots over a period of five to nine years. They found that competition between varieties grown in mixed stands often caused results considerably different from those expected on the basis of the yield performance of the individual varieties grown in pure stands. It was concluded that the relative yield of a variety was not necessarily a criterion of its ability to survive in a mixed population. Such high yielding and rather widely adapted varieties as Vaughn barley and Ramona wheat were found to be poor competitors in mixtures with other varieties having lower individual yields. It was emphasized in this study that it is assumed in the bulk method of breeding cereals that the forces of natural selection favor the perpetuation of plants that are best fitted to survive the hybrid mixture, and that this method likewise will sort out the types that will yield best when grown alone. The authors contend that this assumption is correct when the undesired types are subject to elimination by cold, disease, or other serious adverse factors, but in the absence of such factors valuable material is likely to be lost as a result of competition. The conclusion was made that the behavior of certain varieties in mixtures suggests a decided limitation for the success of the bulk population method of breeding.

Cumulative changes which took place from year to year in a winter wheat varietal population consisting of a mixture of Kanred, Harvest Queen, and Currell were studied by Laude and Swanson (18) at two locations over a nine-year period. The varietal ratios were shifted from equal proportions to nearly pure stands of Kanred, the better adapted variety, in less than nine years. They concluded that the change in varietal ratios was brought about by competition among plants resulting in the survival of a larger proportion of the better adapted variety than of the less well-adapted variety, and by the production of more seeds per plant by surviving plants of the better adapted variety. Klages (17) grew mixtures of three varieties of spring wheat in a single season when stem rust was very severe. An exceptionally large increase in the proportion of the resistant variety Mindum was observed. The large change in mixture components was explained by the particular growing conditions and by the occurence of the severe stem rust epiphytotic. The high yielding wheat variety Tuscan was grown in a mixture with inferior yielding hybrid strains derived from it by Frankel (4). The Tuscan variety was observed to yield better in mixed than in pure stands, while the hybrid strains yielded less in mixed stands.

In a discussion of the theory of small grain breeding, Leighty (19) states that natural selection may be effective in developing a disease resistant variety. He cites the experience with rosette disease of wheat in Illinois in which resistant plants were selected from the susceptible variety Harvest Queen in a badly infested field.

The early literature relative to the inheritance of resistance to crown and stem rust of oats has been summarized by Smith (25). Resistance to stem rust was generally considered to be dominant and inherited on a single factor basis by various investigators in studies involving different crosses. Inheritance of stem rust reaction was found to be independent of other plant characters studied, such as awn development, basal hairs, lemma color and strength of straw. More recent investigations by Hayes, Moore and Stakman (12), Torrie (28), and Cochran, et al. (1) have further established the single factor explanation of resistance to stem rust. Single factor differences were found to govern resistance to stem rust in several crosses studied by

Litzenberger (20), but three factor pairs appeared to be involved in determining resistance in the cross Sac x Hajira-Joanette.

Inheritance of resistance to crown rust of oats has been found to be somewhat more complex than resistance to stem rust. In the early literature summarized by Smith (25) both resistance and susceptibility were reported as dominant depending upon the material studied and both one and two factor differences were obtained by different investigators. Later studies by Hayes, Moore and Stakman (12) indicated resistance to be dominant and in some crosses was governed by a single factor difference while in others it appeared to be due to two complementary factors. Torrie (28) found that the segregation for crown rust reaction, in the cross Iowa No. 444 x Bond, suggested the presence of two factor pairs, a factor for resistance and a factor that partially inhibited the expression of resistance. From one to four factor pairs were found to govern resistance to crown rust in crosses involving different parents studied by Cochran, _et al_. (1). In one cross a set of dominant complementary genes for resistance was carried by the resistant parent and a set of dominant complementary inhibitor genes epistatic to the genes for resistance was carried by the susceptible parent. Litzenberger (20) obtained one, two, and three factor differences for resistance to crown rust in a recent study involving several different oat crosses and found resistance to be dominant in all cases.

MATERIALS AND METHODS

Rust and Helminthosporium Determinations in the Greenhouse

One of the important aspects of this investigation was to obtain information on the effectiveness of natural selection in bulk hybrid oat populations for resistance and susceptibility to crown and stem rust and to Helminthosporium blight. For this purpose a series of tests with rust and Helminthosporium, using seedling plants, were conducted in the greenhouse at Ames, Iowa, during the winter of 1946-47 and in the fall of 1947. Material for these determinations was obtained from replicated rod row yield tests of the bulk hybrids in 1946 by selecting twenty-five panicles from each of the two guard rows in four replicates. This gave a total of 200 F_7 or F_8 panicles for use in determining the rust reaction of each cross. Panicles were selected at six to eight inch intervals in the row to insure that each panicle represented a different plant in the population.

The crosses involved in this study were re-made in the field at Ames in the summer of 1946 and the F_1 seed grown by Dr. N. E. Borlaug of the Rockefeller Foundation at Mexico City, Mexico, during the winter of 1946-47. The limited amount of F_2 seed produced by these plants was then planted in the field at Ames in the summer of 1947 and panicles selected from it for determining the rust reaction of the F_3 generation in the greenhouse in the fall of 1947.

In the greenhouse the seed from each panicle was planted in a four inch flower pot at the rate of twenty to twenty-five seeds per pot. Seedlings were inoculated in the first leaf stage at seven to nine days after planting by placing the plants in a moist chamber, spraying with a fine mist to produce a film of water on the leaves, and then dusting with a mixture of rust spores and talcum. The plants were kept in the moist chamber at ordinary greenhouse temperatures for a period of twenty-four hours. With each group of hybrids several plants of each parent also were inoculated, as a check on the intensity of inoculation and to serve as a guide in the classification of resistant and susceptible segregates.

Rust readings were made ten to fourteen days after the plants were inoculated, the infected primary leaf clipped off, and the same plants re-inoculated, using another physiologic race. Races 1 and 45 of crown rust (*Puccinia coronata avenae* Eriks.) and races 2 and 8 of stem rust (*Puccinia graminis avenae* Eriks. and Henn.) were used in this investigation.

Three of the crosses segregating for the Victoria type of resistance to race 45 of crown rust also were inoculated with *Helminthosporium victoriae* Meehan and Murphy by placing the plants in the moist chamber and dusting pulverized infected straw on the plants and soil as described by Litzenberger and Murphy (21). A twenty-four to thirty hour period in the moist chamber was sufficient to produce infection by the pathogen.

Yield Test of Segregates from Bulk Hybrid Populations

Ten crosses were selected from a group of bulk hybrid oat populations to study the performance of the bulk populations relative to a random group of segregates from the bulk population for yield and other agronomic characters. Yields of the F_2, F_3, F_4, F_5, and F_6 generations in bulk replicated rod row tests were available, and on the basis of these data five crosses were classified as high and five as low in yield. Yields of the ten crosses expressed as a percentage of the average yield of Boone, Tama, and Marion checks for this period are given in Table 1. While the yields of these crosses varied considerably from generation to generation, they were considered to be among the most consistently high or low yielding crosses in the group of seventy from which they were chosen.

In addition to the bulk hybrid seed of the ten crosses, from 60 to 125 individual panicles of each cross had been selected at random in the F_5 or F_6 generation of the bulk

Table 1. Yields of F_2, F_3, F_4, F_5, and F_6 generations of bulked hybrids compared with average yield of Boone, Tama, and Marion in 1941 to 1945.[a]

Cross No.[b]	Cross	Yield expressed as a percentage of average of Boone, Tama, and Marion[c]					
		F_2	F_3	F_4	F_5	F_6	Ave. F_2-F_6
High							
363	(D69-Bond, C.I. 3909) x Bond DCA, C.I. 3646.	112	94	106	108	111	106
409	(D69-Bond, C.I. 3841) x Columbia	145	117	107	109	---	120
358	Columbia x (D69-Bond, C.I. 3843)	119	112	100	115	116	112
375	Sac x Osage	120	117	106	113	---	114
381	(Victoria x Hajira-Banner, C.I. 4020) x D69-Bond, Sel. 2042-8	126	109	97	109	---	110
Low							
366	(D69-Bond, C.I. 3843) x Vanguard	84	99	93	94	110	96
384	(Anthony-Bond, C.I. 3852) x Boone	116	88	92	98	---	99
386	(Victoria x Hajira-Banner, C.I. 4021 x Vikota	92	92	90	105	---	95

Table 1. (Continued)

Cross No.[b]	Cross	Yield expressed as a percentage of average of Boone, Tama, and Marion[c]					
		F_2	F_3	F_4	F_5	F_6	Ave. F_2-F_6
376	Osage x (Victoria x Hajira-Banner, C.I. 4021)	116	105	67	64	---	88
377	(Victoria x Hajira-Banner, C.I. 4022) x Osage	147	114	77	81	---	105

a/ Data from 1945 Annual Report of Cereal Breeding Investigations, Iowa Agricultural Experiment Station, by permission of Dr. H. C. Murphy.

b/ Crosses number 358, 363, and 366 were in F_6 in 1945; other crosses were in F_5 in 1945.

c/ Average yield of Boone, Tama, and Marion was 89.1 bushels.

populations and planted in five foot rows for study in the disease nursery in 1946. By selecting fifty of these segregates at random from each of the ten crosses, together with the bulked seed of each cross and the standard varieties Clinton and Benton, the total number of entries for the yield test was increased to 512. This number of entries made possible the use of an 8 x 8 x 8 cubic lattice design for the field test grown in 1947 at Ames, Iowa.

Three replicates, or one set of the lattice, were grown using the procedure given by Day and Austin (2) for assigning code numbers to the entries. Because the five foot panicle rows grown in 1946 yielded only a limited supply of seed of the fifty segregates of each cross, it was necessary to use single half-rod row plots in the test. The plots were planted at the rate of one gram of seed per foot, to a length of 8.5 feet and trimmed to 7.5 feet prior to harvesting to minimize border effect. Seed of the variety Clinton was drilled in alternate rows to provide uniform competition for the entries in the test and to separate them in case of severe lodging prior to harvest time.

Field notes including date of heading, date of maturity, plant height, coefficients of crown and stem rust infection, and percentage of infection by <u>Helminthosporium victoriae</u> were taken in addition to the yield data. Date of heading was recorded when approximately five per cent of the tillers in a plot had panicles emerging from the boot. These data were expressed as days after May 31. Maturity notes were recorded as number of days after June 30 for the plot to be ready for combine harvesting. The average height of plants was measured in inches from the ground to the highest point on mature plants. As all varieties remained erect or nearly erect throughout the growing season, no lodging notes were obtained.

Inter-generation Correlations

Due to the heterogeneous nature of the bulk populations, detailed agronomic notes were not taken on this group of material during the early segregating generations. Yield from replicated rod row trials and bushel weight data were available, however, for comparing the relative performance of the different bulk populations from generation to generation during the period 1941-45. Coefficients of correlation were calculated between the data obtained for these characters in the F_2, F_3, F_4, F_5, and F_6 generations.

EXPERIMENTAL RESULTS

Rust and Helminthosporium Determinations in the Greenhouse

A summary of the segregation for crown and stem rust reaction in the F_3 generation of four crosses is given in Table 2. Classification for rust reaction was made by placing the lines in three classes, homozygous resistant, homozygous susceptible, and segregating for resistance and susceptibility. Resistance to stem rust was found to be inherited on a single factor basis in each of the four crosses studied, which is in agreement with the work of many investigators. Resistance to race 45 of crown rust also was found to be inherited on a single factor basis in the two crosses studied, while resistance to race 1 of crown rust was found to be governed by two complementary factors, with resistance dominant, in the one cross studied. Only plants homozygous for both dominant factors (AABB) gave a homozygous resistant reaction, while plants with either or both factors recessive (aaBB, aaBb, AAbb, Aabb, aabb) gave a fully susceptible reaction.

Segregations for reaction to crown rust, stem rust, and *H. victoriae* observed in seedlings of F_7 and F_8 bulk hybrid populations appear in Table 3. The calculated values given

Table 2. Segregation in four oat crosses for reaction to crown and stem rust observed in seedlings of F_3 lines grown in the greenhouse.

Cross No.	Cross	Physiologic Race[a]	Observed or Expected[b]	Number of Lines[c] R	Seg	S	Total	X^2	Range of Prob.
375	Sac x Osage	SR8	O	25	46	20	91	0.56	.70-.80
			E	22.75	45.50	22.75			
	"	CR45	O	22	43	26	91	0.63	.70-.80
			E	22.75	45.50	22.75			
384	(Anthony-Bond, C.I. 3852) x Boone	SR8	O	26	49	30	105	0.77	.50-.70
			E	26.25	52.50	26.25			
	"	CR45	O	21	55	29	105	1.46	.30-.50
			E	26.25	52.50	26.25			
358	Columbia x (D69-Bond, C.I. 3843)	SR2	O	12	28	15	55	0.35	.80-.90
			E	13.75	27.50	13.75			
	"	SR8	O	14	29	12	55	0.31	.80-.90
			E	13.75	27.50	13.75			
366	(D69-Bond, C.I. 3843) x Vanguard	SR8	O	8	19	13	40	1.35	.50-.70
			E	10	20	10			
	"	CR1	O	2	24	15	41	1.63	.30-.50
			E	3	20	18			

a. SR = stem rust; CR = crown rust.

b. Expected values for races 2 and 8 of stem rust and race 45 of crown rust calculated from the proportion 1 resistant: 2 segregating: 1 susceptible. Expected values for race 1 of crown rust calculated from the proportion 1 resistant: 8 segregating: 7 susceptible.

c. R = resistant; Seg. = segregating; S = susceptible.

Table 3. Greenhouse reaction to crown rust, stem rust and *H. victoriae* observed in seedlings from individual plants selected at random from F_7 and F_8 bulk hybrid populations.

Cross No.	Cross	Generation	Pathogen[a]	Observed or Expected	Number of Lines[b] R	Seg	S	Total	X^2
375	Sac x Osage	F_7	SR8	O	77	21	102	200	76.9
				E	98	4	98		
			CR45	O	41	18	141	200	94.4
				E	98	4	98		
			H. vict.	O	141	18	41	200	94.4
				E	98	4	98		
384	(Anthony-Bond, C.I. 3852) x Boone	F_7	SR8	O	107	10	83	200	12.8
				E	98	4	98		
			CR45	O	73	20	107	200	71.6
				E	98	4	98		
			H. vict.	O	107	20	73	200	71.6
				E	98	4	98		
358	Columbia x (D69-Bond, C.I. 3843)	F_8	SR8	O	123	15	62	200	104.1
				E	99	2	99		
			SR2	O	121	15	64	200	101.8
				E	99	2	99		

Table 3. (continued).

Cross No.	Cross	Generation	Pathogen[a]	Observed or Expected	Number of Lines[b] R	Seg	S	Total	X^2
366	(D69-Bond, C.I. 3843) x Vanguard	F_8	SR8	O	150	5	45	200	60.3
				E	99	2	99		
			CR1	O	155	9	36	200	339.5
				E	49	2	149		
377	(Victoria x Hajira-Banner, C.I. 4022) x Osage	F_7	SR8	O	143	19	38	200	63.6
				E	98	4	98		
381	(Victoria x Hajira-Banner, C.I. 4020) x D69-Bond, Sel. 2042-8	F_7	CR45	O	43	17	140	200	91.1
				E	98	4	98		
			H. vict.	O	140	17	43	200	91.1
				E	98	4	98		

a. SR = stem rust; CR = crown rust; H. vict. = *Helminthosporium victoriae*

b. R = resistant; Seg. = segregating; S = susceptible in the table represent the breeding behavior expected in later generations of a self-fertilized species on the hypothesis of no selection. In the crosses in which resistance and susceptibility were inherited on a single factor basis, an equal distribution would be expected of the homozygous resistant and susceptible types, with a very few lines still segregating. In the case of the D69-Bond x Vanguard cross in which resistance to race 1 of crown rust was determined to be governed by two complementary factors a large proportion of fully susceptible segregates would be expected in later generations. While no information was obtained from this study on the inheritance of resistance to H. victoriae, the data of Murphy and Meehan (24) and Litzenberger (20) indicate resistance to be inherited on a single factor basis, with susceptibility dominant. The expected values were calculated on this basis.

It is apparent from the data in Table 3 that the forces of natural selection shifted the proportions of resistant and susceptible segregates in the bulk populations from the expected values with random selection. Chi square values in all cases far exceeded the value for a .01 range of probability. During the period 1941-46 in which the bulk populations were grown in replicated yield tests no artificial disease epiphytotics were produced in this material. Any selection in the population should then be dependent upon natural infection and the prevalence of the various physiologic races over this period. The most striking example of the effectiveness of natural selection for resistant types was evident in the segregation of the D69-Bond x Vanguard cross for reaction to race 1 of crown rust. Murphy (23) has shown that races 1 and 6 of crown rust were by far the most prevalent races during this period. Over 50 per cent of all isolates each year were composed of one or a combination of these two races. In two of the seasons in which the bulk populations were grown, 1941 and 1943, natural epiphytotics of crown rust were very severe. The intensity of selection for resistant types under these conditions was very apparent in the observed values.

Natural selection for segregates resistant to races 2 and 8 of stem rust was very effective in the crosses which were not segregating for resistance and susceptibility to _H. victoriae_, namely Columbia x D69-Bond, D69-Bond x Vanguard, and (Victoria x Hajira-Banner) x Osage. Stakman (26) reports that prior to 1943 races 2 and 5 made up more than 97 per cent of all collections of stem rust, and that since 1943 races 8 and 10 have increased in prevalence and become the predominating races in this area. Segregation for resistance and susceptibility to both race 2 and 8 of stem rust was obtained in the cross Columbia x D69-Bond and it was noted in classification that a very high association existed for resistance to the two races. In the material classified, a large majority of the segregates were resistant, susceptible, or segregating for both race 2 and race 8. Such an association of resistance to the two races would tend to add continuity to the effectiveness of natural selection over this period, even though the prevalence of the two races changed materially.

In the three crosses segregating for resistance and susceptibility to *H. victoriae*, crown, and stem rust, i.e. Sac x Osage, Anthony-Bond x Boone, and (Victoria x Hajira-Banner) x D69-Bond, it was apparent that natural selection for resistance to *H. victoriae* was the most effective. This might be expected because susceptibility to *H. victoriae* would tend to remove a plant from the population, i.e., it is more nearly lethal in its effect, than susceptibility to crown or stem rust. The effectiveness of this selection is further emphasized in consideration of the fact that *H. victoriae* was first noticed in the field at Ames in 1945 and was not present in epiphytotic proportions until 1946. Prior to 1945 the bulk populations had been subjected to natural selection for crown and stem rust resistance for a period of five to six years. The very effective natural selection of segregates resistant to crown and stem rust, observed in crosses resistant to *H. victoriae*, was not evident in bulk populations of crosses segregating for reaction to H. victoriae.

When classifying plants resistant and susceptible to race 45 of crown rust and resistant and susceptible to H. victoriae it was observed that all lines with the "Victoria type" of resistance to race 45 of crown rust also were susceptible to H. victoriae. This is in agreement with the observations of Murphy and Meehan (24) and Litzenberger (20). Natural selection for segregates resistant to race 45 of crown rust was then very ineffective due to the greater intensity of selection for types resistant to H. victoriae.

Yield Test of Segregates from Bulk Hybrid Populations

The analysis of variance of the field data was calculated by the punched card machine method for a cubic lattice as given by Homeyer, Clem, and Federer (13). Relative efficiencies, coefficients of variation, average standard errors and differences required for significance obtained for the characters studied were calculated using the formulas given by Homeyer, et al. (13) and are presented in Table 4.

The gain in precision obtained through the use of the cubic lattice design was very small for all characters except plant height. Reduction of the block size from 512 to 8 plots by use of the cubic lattice design resulted in a gain of only eleven per cent in the case of yield, the character of primary concern in this study. In view of this

Table 4. Relative efficiencies, coefficients of variation, average standard errors and least significant differences obtained for yield, maturity, heading date, and plant height of bulk hybrid oat populations grown in an 8 x 8 x 8 cubic lattice design.

Character	Relative efficiency	Coefficient of variation	Average standard error	Least significant difference (5% level)
Yield	111.1%	14.6%	19.6 grams 7.8 bu.	38.5 grams 15.4 bu.
Maturity	115.1%	5.5%	1.11 days	2.18 days
Date of heading	120.0%	3.7%	0.77 days	1.50 days
Plant height	169.3%	3.9%	1.25 inches	2.45 inches

fact the adjustment of variety totals for differences in productivity of the blocks was not deemed warranted and all means presented in this paper were calculated from variety totals unadjusted for block differences. The coefficient of variation obtained for yield was slightly higher than generally observed in rod row trials of oats, but was not considered excessive for half-rod row plots. Coefficients of variation obtained for the other characters analyzed were quite small.

Yield

The analysis of variance of yield in grams per plot is given in Table 5. Since the variety totals were not adjusted the tests for significance of all sources of variation, with

Table 5. Analysis of variance of yield in grams per plot of bulk hybrids and segregates grown in 1947.

Source of variation	Degrees of freedom			Mean square	
Replicates	2			88899.65**	
Varieties	511			5459.12**	
Among selections from crosses		499			5498.43**
Crosses			9		128200.80**
Seg. within crosses			490		3244.71**
Within cross 363 (H)			49		1400.93**
" " 409 (H)			49		1769.55**
" " 358 (H)			49		1971.92**
" " 375 (H)			49		3967.83**
" " 381 (H)			49		3970.56**
" " 366 (L)			49		2118.48**
" " 384 (L)			49		1978.77**
" " 386 (L)			49		6934.67**
" " 376 (L)			49		4425.39**
" " 377 (L)			49		4010.13**
Among remainder		11			2332.27**
Between 10 bulks			9		2847.33**
Checks vs. 10 bulks			1		0.80
Clinton vs. Benton			1		28.17
Between remainder and crosses		1			20237.63**
Blocks (eliminating varieties)	189			1183.87**	
Component a		21			985.83**
" b		21			716.06
" c		147			1279.00**
Error (Intra-block)	833			520.75	
Total	1535				
Error (Randomized blocks)	(1022)			(643.38)	

** Significant at 1% level.

the exception of the block components, were made using the error variance for a randomized block analysis. Highly significant differences in yield were obtained between the ten bulk populations, between the fifty segregates from each cross and among the fifty segregates of each of the ten crosses. The greatest single source of variation was found to occur between the fifty segregates from the ten crosses.

At the time the ten crosses used in this study were selected on the basis of their performance in replicated bulk yield trials, the rapidity with which H. victoriae was to become a major oat disease was not fully anticipated. The yield data upon which the original classification was based were obtained during the period 1941-45 in which H. victoriae was not present in epiphytotic proportions. The yield test of segregates from the ten bulk populations, however, was grown in 1947 and H. victoriae had by that time become a widespread and very severe disease of oats, affecting mainly varieties and selections possessing the Victoria-type of resistance to crown rust. Of the ten crosses used in this study six were Victoria derivatives and four did not contain Victoria germ plasm.

Field notes on the percentage of plants per plot infected by H. victoriae were taken prior to heading and rechecked prior to maturity on all three replicates. From 5 to 70 per cent of the plants per plot were found to be infected by _H. victoriae_ in five of the crosses containing Victoria germ plasm. The four crosses which were not Victoria derivatives and the cross Anthony-Bond x Boone (Cross No. 384) were given a zero reading in all plots for percentage of infected plants. Previous greenhouse studies of the Anthony-Bond x Boone cross had indicated it to be segregating for the Victoria-type of resistance to crown rust and consequently susceptibility to _H. victoriae_ under greenhouse conditions. The reason for the absence of susceptible selections in this cross under field conditions is not clear. The severity of infection by _H. victoriae_ has been observed by Murphy (23) to be greater under conditions of artificial inoculation in the greenhouse than under field conditions, but some infection should be evident in the field. It is possible that infection in this cross was very slight and was masked by other leaf discolorations at the time the readings were taken; or that infection did not develop until very late in the season in this cross and was not apparent at the time the readings were made. On the other hand, the yield range and variance of the segregates of this cross compared favorably with those obtained from the segregates of the four crosses which did not contain Victoria germ plasm. Further investigation of this cross would then seem necessary, but for purposes of comparison in this paper it is placed with the four non-Victoria types and classified as resistant to H. victoriae.

Frequency distributions of the yields and the mean squares obtained for the five resistant crosses as compared with the five crosses containing susceptible segregates are presented in Table 6. It is evident that the range in yield and the variance of the five crosses with susceptible segregates was considerably greater than for the five resistant crosses, and that the mean yield of the five crosses containing susceptible segregates was significantly less than the mean yield of the five resistant crosses.

The yields and percentage of infection by H. victoriae of all susceptible segregates in the five segregating crosses were utilized in calculating coefficients of correlation and regression between these characters. A highly significant negative correlation, $r = -0.803$ (143 d.f.), and a regression coefficient of yield in grams on percentage of infection by H. victoriae of -2.0233 were obtained. By converting grams to bushels per acre the regression coefficient between yield in bushels per acre and H. victoriae was -.3097. Yields of the susceptible segregates were then adjusted by multiplying the percentage of infection by H. victoriae by the regression coefficient and adding this value to the original yield in grams. Frequency distributions of the yields of resistant and susceptible segregates from the five segregating crosses after the yields of susceptible segregates had been adjusted

Table 6. Frequency distribution of yield in grams of segregates from five bulk hybrid populations resistant to *H. victoriae* and five bulk hybrid populations segregating for resistance to *H. victoriae*, expressed as standard errors above or below the mean of Clinton and Benton.[a]

Cross No.	-8	-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	Mean Yield, Bu/acre[b]	Mean Square
Res.														
366						3	9	8	17	8	5		76.5	2118.48
363						2	5	15	22	5	1		75.0	1400.93
409						3	12	13	15	4	3		73.2	1769.55
384					5	5	11	17	9	3			67.7	1978.77
358					2	1	9	13	14	10	1		74.1	1971.92
Seg.														
375			2	2	7	7	4	14	12	2			64.4	3967.83
386		1	3	2	7	3	3	8	8	10	5		68.5	6934.67
381	1		2	1	2	3	13	15	8	4	1		70.8	3970.56
376		3	10	13	6	5	5	7	1				47.5	4425.39
377	1	4	13	15	6	5	1	4	1				42.1	4010.13
5 Resistant					7	14	46	66	77	30	10		73.3	9239.65
5 Segregating	2	8	30	33	28	23	26	48	30	16	6		57.8	23308.58

a. Mean yield of Clinton and Benton = 75.0 bu.

b. Least significant difference between cross means (5%) = 2.2 bu., (1%) = 2.9 bu. Least significant difference between means of five resistant and five segregating crosses (5%) = 1.0 bu., (1%) = 1.3 bu.

by regression are given in Table 7. The adjusted yields of the susceptible segregates were still somewhat lower than the yields of resistant segregates in all five crosses. This would tend to indicate that the resistant types also were the higher yielding types in the bulk population, but it is not known whether this relationship would be borne out if the population was grown in the complete absence of the disease organism.

By pooling the adjusted yields of the susceptible segregates and the unadjusted yields of the resistant segregates in each of the five segregating crosses, it was possible to make the originally intended comparison of five high and five low yielding crosses on the basis of fifty segregates from each population. Frequency distributions of yields of segregates from the five high and five low yielding crosses are given in Table 8. Considerable deviation of the yields of the segregates and the bulk populations from those which might be expected are apparent in this table. Calculation of the exact number of bushels required for statistical significance between the mean of the five high and five low yielding crosses was not possible without recalculation of the data using the adjusted totals for the segregates susceptible to H. victoriae. The difference necessary for significance between means of the same number of items prior to adjustment (1.0 bushels) was very small. It is quite

Table 7. Frequency distributions of yield in grams of segregates from five bulk hybrid oat populations segregating for resistance to *H. victoriae*, expressed as standard errors above or below the mean of Clinton and Benton[a]; yields of susceptible segregates adjusted by regression.[b]

Cross No.	Res. or Susc.	-5	-4	-3	-2	-1	0	+1	+2	+3	Total No.	Mean Yield Bu/acre
375	Res.			1	2	12	12	2			29	74.2
	Susc.	1	1	4	10	5					21	61.9
381	Res.			2	12	15	7	3	1		40	70.7
	Susc.		1	2	4	2			1		10	63.6
386	Res.			1	2	6	8	9	5		31	80.4
	Susc.			6	7	4		2			19	64.2
376	Res.			1		2					3	67.6
	Susc.		4	16	13	10	4				47	62.0
377	Res.					1	1				2	78.2
	Susc.		1	15	17	13	2				48	62.6
All resistant				5	16	36	28	14	6		105	74.2
All susceptible		1	7	43	51	34	6	2	1		145	62.9

a. Mean yield of Clinton and Benton = 75.0 bushels

b. Regression coefficient of yield in grams per plot on percentage infection by *H. victoriae* = -2.0233 grams

Table 8. Frequency distribution of yield in grams of segregates from five high and five low yielding bulk hybrid oat populations expressed as standard errors above or below the mean of Clinton and Benton[a]; yields of segregates susceptible to *H. victoriae* adjusted by regression.[b]

Cross No.	-5	-4	-3	-2	-1	0	+1	+2	+3	Mean Yield of segregates Bu./Acre	Mean Yield of Bulk Populations
High											
363				2	5	15	22	5	1	75.0	84.5
409				3	12	13	15	4	3	73.2	94.0
358			2	1	9	13	14	10	1	74.1	65.1
375		1	1	5	12	17	12	2		69.0	79.9
381			1	4	16	17	7	3	2	69.0	76.5
Low											
366				3	9	8	17	8	5	76.5	77.2
384			5	5	11	17	9	3		67.7	86.0
386				7	9	10	8	11	5	74.2	75.0
376			4	17	13	12	4			62.4	73.9
377			1	15	17	14	3			63.3	65.1
5 High		1	4	15	54	75	70	24	7	72.1	80.0
5 Low			10	47	59	61	41	22	10	68.9	75.6

a. Mean yield of Clinton and Benton = 75.0 bu.

b. Regression coefficient of yield in grams per plot on percentage infection by *H. victoriae* = -2.0233 grams likely that the difference between the mean of the two groups is statistically significant, based on 250 selections in each group. However, from a practical point of view the difference (3.2 bushels) between the means of the five high and five low yielding crosses is comparatively small.

From Table 8 it is apparent that the mean yields of the segregates from cross Nos. 366 and 386 of the low yielding group compared favorably with the mean yields of segregates from the three highest yielders of the high yielding group. Yield ranges of segregates from all crosses were not appreciably different, and if the number of segregates yielding more than one standard error above the mean of Clinton and Benton are counted, it is found that thirty-one are from the high yielding group and thirty-two are from the low yielding group. Similarly, if the number of segregates yielding more than two standard errors above the mean of Clinton and Benton are counted, seven are from the high yielding group and ten from the low yielding group. The data in Table 8 do not substantiate the contention that the bulk populations which give the highest yields in replicated tests in the early segregating generations will also produce the largest proportion of high yielding segregates when selections are made in later generations. It also was evident that the yield performance of bulk populations in the 1947 test was not in all cases in agreement with their relative performance in the previous bulk yield trials. Considerable variation is apparent between the relative yield rank of the ten bulk populations and the rank of the fifty segregates from each bulk population when grown in the same year. Such variable results within a single season together with the variable early generation yield performance of the bulk populations would indicate that such data may not be sufficiently reliable for use in evaluating the yielding potentialities of segregates selected from bulk populations.

Heading date

The analysis of variance of date of heading of the bulk populations and segregates from the bulk populations is given in Table 9. As in the analysis of variance of the yield data the tests of significance of all sources of variation, with the exception of the block components, were made using the error variance for a randomized block analysis. This procedure also was followed in testing the significance of differences in maturity and plant height reported in subsequent sections. Highly significant differences in date of heading were obtained between the ten bulk populations, between the fifty segregates from each cross and within the fifty segregates of each of the ten crosses. The greatest proportion of the variance was attributable to variation between the fifty segregates from the ten crosses.

Table 9. Analysis of variance of heading date, expressed as days after May 31, of bulk hybrids and segregates grown in 1947.

Source of variation	Degrees of freedom				Mean Square	
Replicates	2				10.39**	
Varieties	511				34.70**	
Among selections from crosses		499				35.00**
Crosses			9			271.38**
Seg. within crosses			490			30.66**
Within cross 363 (H)				49		15.73**
" " 409 (H)				49		23.65**
" " 358 (H)				49		21.46**
" " 375 (H)				49		29.19**
" " 381 (H)				49		15.13**
" " 366 (L)				49		58.95**
" " 384 (L)				49		17.25**
" " 386 (L)				49		21.78**
" " 376 (L)				49		61.01**
" " 377 (L)				49		42.40**
Among remainder		11				11.23**
Between 10 bulks			9			10.16**
Checks vs. 10 bulks			1			32.09**
Clinton checks vs. Benton			1			0.00
Between remainder and crosses		1				141.81**
Blocks (eliminating varieties)	189				2.31**	
Component a		21				2.27**
" b		21				1.18
" c		147				2.48**
Error (Intra-block)	833				0.78	
Total	1535					
Error (Randomized blocks)	(1022)				(1.06)	

** Significant at 1% level.

Coefficients of correlation and regression were calculated between date of heading and percentage of infection by <u>H. victoriae</u> of all susceptible segregates in the five segregating crosses. A highly significant negative correlation, $r = -0.925$, and a regression coefficient of heading date on percentage of infection by <u>H. victoriae</u> of -0.0201 were obtained. Heading dates of the susceptible segregates were adjusted by use of the regression coefficient as described for the yield data. Frequency distributions of heading dates of segregates from the five high and five low yielding crosses, using the adjusted values for the susceptible segregates and the unadjusted values of the resistant segregates, are presented in Table 10. No pronounced trend toward earliness or lateness of heading of segregates from either the high or low yielding crosses is apparent from the data.

Maturity

The significance of differences in maturity of the bulk populations and their segregates may be observed in the analysis of variance for this character presented in Table 11. Highly significant differences in date of maturity are apparent between the ten bulk populations, between the fifty segregates from each cross and among the fifty segregates of each of the ten crosses. Variation between the fifty segregates from the ten crosses accounted for a considerable

Table 10. Frequency distribution of dates of heading of segregates from five high and five low yielding bulk hybrid oat populations, with heading dates of segregates susceptible to H. victoriae adjusted by regression.[a]

Cross No.	Days after May 31 (16-17)	(18-19)	(20-21)	(22-23)	(24-25)	(26-27)	(28-29)	(30-31)	(32-33)	(34-35)	Mean heading date of segs.	Mean heading date of bulk pop's.
High												
363			12	17	11	10					23.22	23.67
409		1	2	12	6	18	9	1	1		25.47	20.67
358		1	8	10	14	11	6				24.07	23.00
375		1	2	12	9	14	7	3		2	25.73	22.33
381				4	22	11	7	4	2		26.12	24.67
Low												
366	1		3	18	3	5	9	6	1	4	25.97	21.00
384					7	16	15	10		2	27.95	26.00
386				7	8	10	17	8			26.86	24.33
376	1	9	4	4	7	9	9	3	3	1	24.98	21.33
377	1		6	4	7	8	10	12	2		26.47	25.00
5 High		3	24	55	62	64	29	8	3	2	24.92	22.87
5 Low	3	9	13	33	32	48	60	39	6	7	26.45	23.53

a. Regression coefficient of heading date on percentage infection by H. victoriae = -0.0201 days.

Table 11. Analysis of variance of maturity, expressed as days after June 30, of bulk hybrids and segregates grown in 1947.

Source of variation	Degrees of freedom				Mean square	
Replicates	2				22.38**	
Varieties	511				40.34**	
Among selections from crosses		499				40.43**
Crosses			9			423.08**
Seg. within crosses			490			33.40**
Within cross 363 (H)				49		16.93**
" " 409 (H)				49		33.31**
" " 358 (H)				49		20.42**
" " 375 (H)				49		36.42**
" " 381 (H)				49		21.24**
" " 366 (L)				49		40.63**
" " 384 (L)				49		28.41**
" " 386 (L)				49		35.15**
" " 376 (L)				49		64.37**
" " 377 (L)				49		37.14**
Among remainder		11				27.36**
Between 10 bulks			9			20.52**
Checks vs. 10 bulks			1			113.61**
Clinton vs. Benton			1			2.66
Between remainder and crosses		1				135.45**
Blocks (eliminating varieties)	189				4.31**	
Component a		21				4.15**
" b		21				2.46
" c		147				4.59**
Error (Intra-block)	833				1.65	
Total	1535					
Error (Randomized blocks)	(1022)				(2.14)	

** Significant at 1% level.

amount of the total variance.

Using the dates of maturity and percentage of infection by *H. victoriae* of all susceptible segregates from the five segregating crosses, coefficients of correlation and regression were calculated. A highly significant negative correlation, r = -0.539, and a regression coefficient of maturity on percentage of infection by *H. victoriae* of -0.1442 were obtained. A comparison of the relative maturity of the five high and five low yielding crosses, after adjusting the maturity of the susceptible segregates by regression, is presented in Table 12. As was the case with date of heading, there appears to be no definite trend toward early or late maturity of segregates from either the high or low yielding bulk populations.

Plant height

The analysis of variance of plant height in inches of bulk populations and segregates from the bulk populations is given in Table 13. Highly significant differences in plant height are evident between the ten bulk populations, between the fifty segregates from each cross and among the fifty segregates of each of the ten crosses, as was the case with the other characters studied. The greatest single source of variation again was found to occur between the fifty segregates from the ten crosses.

Table 12. Frequency distribution of dates of maturity of segregates from five high and five low yielding bulk hybrid oat populations, with maturity of segregates susceptible to *H. victoriae* adjusted by regression.[a]

Cross No.	Days after June 30 (16-18)	(19-21)	(22-24)	(25-27)	(28-30)	(31-33)	(34-36)	Mean maturity of segregates	Mean maturity of bulk populations
High									
363		5	17	21	7			24.83	25.67
409		8	13	14	13	2		25.20	27.67
358	1	9	20	19	1			23.69	24.67
375	1	2	13	14	17	3		26.03	29.00
381		3	31	13	1	2		24.17	28.67
Low									
366	2	13	17	8	8	2		23.81	25.33
384			3	16	16	11	4	28.99	33.67
386		2	18	19	8	3		25.45	27.33
376		6	9	12	16	6	1	26.77	27.67
377		2	7	21	16	3	1	26.77	29.33
5 High	2	27	94	81	39	7		24.78	27.14
5 Low	2	23	54	76	64	25	6	26.36	28.67

a. Regression coefficient of maturity on percentage infection by *H. victoriae* = -0.1442 days.

Table 13. Analysis of variance of plant height in inches of bulk hybrids and segregates grown in 1947.

Source of variation	Degrees of freedom				Mean square	
Replicates	2				119.58**	
Varieties	511				40.74	
Among selections from crosses		499				41.20**
Crosses			9			972.40**
Seg. within crosses			490			24.10**
Within cross 363 (H)				49		13.19**
" " 409 (H)				49		19.75**
" " 358 (H)				49		26.84**
" " 375 (H)				49		42.14**
" " 381 (H)				49		23.46**
" " 366 (L)				49		21.49**
" " 384 (L)				49		15.78**
" " 386 (L)				49		22.26**
" " 376 (L)				49		33.03**
" " 377 (L)				49		23.02**
Among remainder		11				15.18**
Between 10 bulks			9			12.98**
Checks vs. 10 bulks			1			2.01
Clinton vs. Benton			1			48.17**
Between remainder and crosses		1				92.92**
Blocks (eliminating varieties)	189				12.61**	
Component a		21				17.26**
" b		21				5.68*
" c		147				12.93**
Error (Intra-block)	833				1.97	
Total	1535					
Error (Randomized blocks)	(1022)				(3.94)	

* Significant at 5% level.

** Significant at 1% level.

Coefficients of correlation and regression were calculated between plant height and percentage of infection by *H. victoriae* as described in previous sections. A highly significant negative correlation, $r = -0.569$, and a regression coefficient of plant height on percentage of infection by *H. victoriae* of -0.1334 were obtained. Frequency distributions of plant height of segregates from the five high and five low yielding crosses, after adjustment of the height of susceptible segregates as previously described, are presented in Table 14. Neither the high nor the low yielding bulk populations exhibited any tendency to consistently yield tall or short segregates.

Parent - progeny range studies

Data presented in previous sections indicated a rather poor agreement between information obtained from early generation bulk hybrid tests and the subsequent performance of segregates from such populations. The question then arose as to whether there was any association between the extent of diversity between the parents of such hybrid and the range obtained among segregates selected from them. Yield, plant height, and maturity data were available for both parents of five of the crosses used in this study for the period 1942-47. A summary of these data together with the

Table 14. Frequency distribution of height in inches of segregates from five high and five low yielding bulk hybrid oat populations, with height of segregates susceptible to H. victoriae adjusted by regression.[a]

Cross No.	Plant height in inches (31-32)	(33-34)	(35-36)	(37-38)	(39-40)	(41-42)	(43-44)	(45-46)	(47-48)	Mean height of segregates	Mean height of bulk populations
<u>High</u>											
363		4	17	12	13	4				37.27	41.00
409			3	5	15	10	9	8		40.89	41.33
358			3	7	10	12	9	6	3	41.38	42.33
375	1	5	8	10	10	3	9	4		38.91	41.67
381				3	5	6	19	15	2	43.19	43.33
<u>Low</u>											
366		2	11	12	10	12	3			38.58	39.00
384			2	16	16	8	6	2		39.67	40.33
386		1	5	13	20	5	5	1		39.13	41.67
376		3	3	14	17	12	1			38.89	39.33
377	1	5	11	15	13	3	1		1	37.67	39.33
5 High	1	9	31	37	53	35	46	33	5	40.33	41.93
5 Low	1	11	32	70	76	40	16	3	1	38.79	39.93

a. Regression coefficient of plant height on percentage infection by <u>H</u>. <u>victoriae</u> = -0.1334 inches.

range obtained in their segregates is given in Table 15.

The range obtained among the fifty segregates for yield and plant height was found to be nearly the same for all crosses irrespective of the extent to which the parents differed. The difference in yield range of segregates from cross Nos. 358 and 375, for example, was only three bushels, while the parental range of the two crosses was twenty bushels. A similar difference in yield range of segregates from cross Nos. 358 and 409 was obtained although the parental range difference between these two crosses was only one bushel. The extent of difference in yield and plant height of the parents involved in a cross would then appear to be of no value in predicting the range expected in a random group of segregates from a bulk population of that cross.

A slight tendency was indicated for crosses with the smaller maturity range between parents to be associated with the larger maturity range of segregates. Cross No. 366 exhibited the smallest parental range and the greatest range between segregates. Cross No. 384, however, showed a parental range equally as small as cross No. 375, but also exhibited the smallest maturity range between segregates. A significant association between the maturity range between parents and the maturity range of the segregates could not be demonstrated statistically.

Table 15. Range in yield, plant height, and maturity of parents and segregates of five bulk hybrid oat populations.[a]

Cross No.	Cross	Mean yield in bu. 1942-47 ♀ parent	Mean yield in bu. 1942-47 ♂ parent	Yield range 1947 50 segregates	Range in yield Between parents	Range in yield Among segregates
358	Columbia x (D69-Bond, C.I. 3843)	65.6	86.4	48.3-91.6	20.8	43.3
375	Sac x Osage	75.2	74.5	43.1-89.2	0.7	46.1
409	(D69-Bond, C.I. 3841) x Columbia	87.5	65.6	53.7-95.7	21.9	42.0
366	(D69-Bond, C.I. 3843) x Vanguard	86.4	66.6	52.5-94.7	19.8	42.2
384	(Anthony-Bond, C.I. 3852) x Boone	78.2	68.0	46.3-87.1	10.2	40.8
		Mean height in in. 1943-46 ♀ parent	**Mean height in in. 1943-46 ♂ parent**	**Height range 1947 50 segregates**	**Range in height Between parents**	**Range in height Among segregates**
358	Columbia x (D69-Bond, C.I. 3843)	34	38	36-48	4	12
375	Sac x Osage	43	31	33-44	12	11
409	(D69-Bond, C.I. 3841) x Columbia	39	34	35-46	5	11
366	(D69-Bond, C.I. 3843) x Vanguard	38	42	34-44	4	10
384	(Anthony-Bond, C.I. 3852) x Boone	38	35	36-46	3	10

Table 15. (continued).

Cross No.	Cross	Mean maturity in July 1943-46: ♀ parent	Mean maturity in July 1943-46: ♂ parent	Maturity range 1947: 50 segregates	Range in maturity: Between parents	Range in maturity: Among segregates
358	Columbia x (D69-Bond, C.I. 3843)	14	25	18-30	11	12
375	Sac x Osage	22	15	17-32	7	15
409	(D69-Bond, C.I. 3841) x Columbia	28	14	19-33	14	14
366	(D69-Bond, C.I. 3843) x Vanguard	25	22	15-32	3	17
384	(Anthony-Bond, C.I. 3852) x Boone	24	17	24-35	7	11

a. Parental data from 1942-47 Annual Reports of Cereal Breeding Investigations, Iowa Agricultural Experiment Station, by permission of Dr. H. C. Murphy.

Inter-generation Correlations

Inter-generation correlation coefficients for yield and bushel weight in each of three groups of bulk hybrids appear in Table 16. The correlations between the yield performance of the bulk hybrids from generation to generation are, with a few exceptions, consistently low and non-significant. Even a slight negative correlation was obtained in two of the comparisons. Bushel weight was found to be more highly correlated in successive generations than was yield. Highly significant positive correlations were obtained in a majority of the comparisons, and all but one of the non-significant values were obtained in group three in which tests of significance were based on only eleven degrees of freedom.

Seasonal conditions during 1941-45 varied considerably from year to year. Severe natural epiphytotics of crown rust occurred in 1941 and 1943, and an abnormally wet and cold spring made the 1944 season a poor one for maximum oat yields. The 1942 and 1945 seasons provided more nearly normal growing conditions for the oat crop. It is apparent from these correlations that fluctuations in environmental conditions are expressed to a much greater degree in yield than in bushel weight. Conclusions on the relative yield potentialities of bulk hybrid oat populations based on their performance in one or two of the early segregating

Table 16. Coefficients of correlation between generations grown in successive years for yield and bushel weight in each of three groups of bulk hybrid oat populations.[a]

Generations correlated[b]	Yield Group 1 35 df	Yield Group 2 18 df	Yield Group 3 11 df	Bushel weight Group 1 35 df	Bushel weight Group 2 18 df	Bushel weight Group 3 11 df
F_2-F_3	.305	.844**	.528	.554**	.722**	---
F_3-F_4	-.072	.367	.383	.683**	.763**	.521
F_4-F_5	.416*	---	.206	.478**	---	.216
F_5-F_6	---	---	.568*	---	---	.370
F_2-F_4	.116	.337	.564*	.673**	.666**	---
F_2-F_5	-.013	---	.243	.416*	---	---
F_2-F_6	---	---	.260	---	---	---
F_3-F_5	.078	---	.128	.284	---	.699**
F_3-F_6	---	---	.311	---	---	.202
F_4-F_6	---	---	.485	---	---	.545

a. Data for calculations from 1941-45 Annual Reports of Cereal Breeding Investigations, Iowa Agricultural Experiment Station, by permission of Dr. H. C. Murphy.

b. Group 1, F_5 in 1945; Group 2, F_4 in 1945; Group 3, F_6 in 1945.

* Significant at 5% level.
** Significant at 1% level.

generations are likely not to be substantiated in subsequent generations. Prediction of bushel weight of bulk hybrids in later generations from early generation data appears to be a valid procedure.

DISCUSSION

The effectiveness of the forces of natural selection in obtaining a high proportion of disease resistant types in the advanced generations of bulk hybrid oat populations is demonstrated quite conclusively by the results obtained in the greenhouse phases of this investigation. Such selection is of course effective for only those diseases and physiologic races of disease organisms which are of considerable natural prevalence during the period of selection. The greater the prevalence of the pathogen, and the more pronounced its effect upon the plant, the greater will be the effectiveness of selection for resistant types. With the crosses used in this investigation it was found that after seven or eight generations of natural selection, a random sample of segregates from the bulk population yielded from 54 to 78 per cent resistant types. Under conditions of no selection 48 per cent resistant types would be expected in the crosses in which resistance was governed by a single factor difference, and only 25 per cent in the one case in which resistance was due to two complementary factors.

A point for speculation is evident in the classification of selections as homozygous resistant, segregating and homozygous susceptible presented in Table 3. In nearly every case the number of selections classified as segregating for resistance and susceptibility was considerably larger than the expected value. Whether this difference was due to chance in sampling or whether the approach toward homozygous types in bulk populations is not as rapid as expected is difficult to say. The consistency and size of the deviations from the expected were of such magnitude that attributing them to chance in sampling does not seem valid. One explanation for the increase might be that the forces of natural selection which have been shown to favor the perpetuation of resistant types may also favor the heterozygous types in a bulk population. With resistance dominant the heterozygous resistant and the homozygous resistant types would be expected to have equal value in survival. Thus the bulk population is not a normal population, in the strict sense of the word, but is biased toward a preponderance of resistant and segregating types at the expense of the susceptible types. Random samples taken from such a population might then be expected to yield a higher proportion of segregating types in advanced generations than one would expect on a purely mathematical basis with no selection involved.

The investigations reported in this thesis and results of previous investigators have shown the bulk method to be of value in developing disease resistant types, winterhardy strains, or types resistant to other adverse conditions. The main point of contention has been, however, as to whether these disease resistant types that compete well in mixed populations also have the highest inherent yielding potentialities when grown in pure stands. In the comparison of the yields of resistant and susceptible segregates from the five segregating crosses used in this investigation (Table 7) it is evident that the resistant types consistently outyielded the susceptible segregates, even after the yields of the susceptible types had been corrected, in so far as possible, for loss in yield attributable to infection by _H. victoriae_. The correlation between yield and percentage of infection by _H. victoriae_ of -0.803 was large enough that a considerable proportion of the variation in yields of susceptible segregates was due to regression. Yields of resistant types and the adjusted yields of susceptible segregates may then be considered to be on a comparable basis. It would be of interest to know how the resistant and susceptible segregates might yield in the complete absence of disease, in comparison with their relative performance under the conditions of this study. However, it seems doubtful that any practical breeding program could be completely divorced from the disease problem and consequently conclusions drawn under disease free conditions would be of limited practical value to the plant breeder.

Experiments conducted with barley and wheat have indicated yield data obtained from bulk populations in the early segregating generations to be of value in predicting which crosses will yield a high proportion of high yielding segregates. The classification of the bulk hybrid oat populations used in this study as potentially high or low yielding on the basis of early generation bulk yield data did not prove successful. Equally as many high yielding segregates were obtained from the potentially low yielding crosses as from the high yielding ones. Of the ten crosses studied the two which yielded the greatest proportion of superior yielding segregates had been classified as potentially poor yielders and might well have been discarded from a breeding program. Bulk yields of these two crosses in the year in which the yield test of segregates was conducted were rather poor, as the previous data had indicated. As both of the crosses concerned were at least predominantly resistant to H. victoriae and crown and stem rust infection was negligible, it would seem that the greater part of the differences in yield of the bulk population and segregates from this material must be attributed to competition differences. The highest yielding types when grown in pure stands are apparently not necessarily the best competitors when grown in bulk populations. Similar conclusions have been reported by Suneson and Wiebe (27) in experiments with mixed populations of wheat and barley.

It should be pointed out, however, that the yield performance of segregates from certain of the crosses studied was in good agreement with the previous performance of the bulk population. Thus it appears that some segregates do well in bulk populations as well as when grown alone, some segregates do poorly under both conditions, some do well in bulk populations and poorly when grown alone, and vice versa. Such variable performances of different hybrid populations indicate ample opportunity for selection of high yielding segregates by the bulk method. On the other hand, an equally large proportion of potentially high yielding segregates may be lost in crosses discarded due to poor bulk yield performance. With the oat breeding program advanced to the stage where increases above an acceptable yield level are being sought, breeding practices should be such that as many as possible of the superior yielding segregates are retained in the breeding program. Results obtained in this investigation suggest that the value of the bulk method may be somewhat limited under these conditions.

No association between heading date, date of maturity or plant height of segregates from bulk populations and the early generation yield performance of the bulk material was observed. As oats are a short-season crop, differences in date of heading and maturity might be expected not to be as closely associated with yield as is the case with full-season crops. In such crops as soybeans and corn the late maturing types are often decreased in yield by an early frost or other adverse conditions toward the end of the growing season. Length of the growing season for oats is such that both early and late types generally have sufficient time, moisture and nutrients for normal maturation of the grain. Considerable range in plant height is exhibited among established high yielding varieties. The lack of association between the height of segregates from the bulk population and the yield classification of the bulk material was, therefore, not unexpected.

Correlations obtained between yield of bulk hybrids in successive early generations indicated such data to be of little value in evaluating the yield performance of those hybrids in subsequent generations. Conclusions as to the yield potentialities of a cross on the basis of one or two seasons performance in bulk trials do not appear warranted. Evaluations of yield potentialities of ten oat crosses on the basis of four to five years bulk yield data were not consistently substantiated in this investigation. The inconsistency of results may be attributed to the highly differential response of segregates in a bulk population to varied environmental conditions encountered in the different seasons. Types which are competitively favored in one season may be reduced in extent under different seasonal conditions. Bushel weight determinations on bulk material appear to be less subject to such environmental fluctuations. Certain of the diseases and adverse environmental conditions which cause a reduction in the amount of grain produced do not result in a proportional decrease in plumpness of the grain which does develop. Reliable conclusions as to the bushel weight of bulk hybrids in later generations may then be drawn from data obtained in one or two of the early segregating generations.

The value of parental differences in yield, maturity and plant height for predicting the range expected for these characters in segregates from a cross was investigated. It would seem that a greater range would be available for selection in crosses between widely different parents than in a hybrid population involving very similar parents. This was not substantiated by the data. Very similar ranges in yield, maturity and plant height were obtained regardless of the magnitude of parental differences for these characters. Yield differences between parental varieties of soybeans have been similarly observed by Kalton (16) to be a poor indication of subsequent bulk population yield performance.

The use of the cubic lattice design in experiments with pine seedlings, soybeans and cotton was cited by Green (5). Gains in efficiency over a randomized complete block design obtained in these experiments ranged from 0 to 15 per cent for the different characters studied. In his own investigations with maize he obtained gains in efficiency in yield determinations of 33 and 184 per cent in two successive years. It was concluded that the cubic lattice is a useful design for testing a large number of strains or varieties of maize. In the present investigations with oats the gains in efficiency obtained from the use of the cubic lattice design were rather small for all characters studied, with the exception of plant height. On the basis of these results the value of the cubic lattice design in oat yield trials appears to be limited. It should be pointed out, however, that single half-rod row plots were used in these studies, and hence the land area involved was considerably less than would normally be used in ordinary nursery tests of a comparable number of selections. If the standard three-rod row small grain plot were used it may be that gains in efficiency comparable to those reported in the corn investigations could be obtained with the cubic lattice design.

SUMMARY AND CONCLUSIONS

1. Segregates from the F_3, F_7, and F_8 generations of bulk hybrid oat populations were tested in the greenhouse for reaction to specific races of crown and stem rust and for reaction to H. victoriae. Bulk F_7 and F_8 populations of ten oat crosses and fifty segregates from each bulk population were grown in the field and evaluated for yield, date of heading, date of maturity, and plant height.
2. Resistance to races 2 and 8 of stem rust and to race 45 of crown rust was inherited on a single factor basis in all crosses studied. Inheritance of resistance to race 1 of crown rust was governed by two complementary factor pairs, with resistance dominant, in the one cross studied. All lines possessing the "Victoria type" of resistance to race 45 of crown rust were susceptible to H. victoriae.
3. The forces of natural selection were very effective in increasing the proportion of disease resistant types in advanced generations of bulk populations. The intensity of such selection was proportional to the prevalence and severity of infection of the specific diseases.

4. Bulk populations which gave the highest yields in replicated tests in the early segregating generations did not produce the greatest proportion of high yielding segregates in subsequent generations. These results suggest that considerable high yielding germ plasm may be lost if bulk crosses are discarded on the basis of early generation yield performance.
5. No association was evident between heading date, maturity or plant height of segregates from bulk populations and the previous yield performance of the bulk population.
6. In crosses segregating for resistance and susceptibility to *H. victoriae* the resistant segregates outyielded the susceptible even when the yields of susceptible segregates had been adjusted by regression for loss in yield due to *H. victoriae*. This would tend to substantiate the hypothesis that disease resistant types also are the high yielding types.
7. Correlations between successive generations for yield of bulk hybrid populations were consistently low and nonsignificant. Predictions of yield performance of bulk hybrids from their performance in previous generations appear to be of limited value. Bushel weight was highly correlated in successive generations and valid conclusions may be drawn from bushel weights obtained in early generations.

8. The extent of difference in yield, maturity and plant height of parental varieties involved in a cross was of no value in predicting the range obtained for these characters in a random group of segregates from a bulk population of that cross.
9. The cubic lattice design appears to be of limited value in the testing of a large number of oat varieties in half-rod row plots.
10. Final evaluation of the merits of the bulk method of breeding oats can not be accomplished until more extensive experiments have been conducted over a period of years.

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APPENDIX

Table I. Agronomic and pathological data obtained on segregates from ten bulk hybrid oat populations, on the ten bulk populations, and on Clinton and Benton checks grown in 1947.

Cross No.	Code No.	Cross	Yield in grams per 3 row plot	Plant ht. in inches per row plot	Maturity date total per 3 row plot	Heading date total per 3 row plot
366	163	(D69-Bond, C.I. 3843) x Vanguard	655	122	80	93
	168		479	120	94	102
	225		624	123	75	84
	232		614	128	78	86
	281		616	106	59	63
	311		671	126	83	92
	312		710	112	72	80
	323		501	117	68	77
	338		641	121	89	97
	355		420	104	66	72
	363		550	124	89	103
	364		592	118	71	73
	378		552	126	75	90
	384		588	126	83	93
	387		429	123	96	107
	411		592	116	69	81
	454		564	122	78	85
	467		609	108	68	67
	474		619	113	65	67
	518		486	117	60	64

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot	Plant ht. in inches per 3 row plot	Maturity date total per 3 row plot	Heading date total per 3 row plot
366	527	(D69-Bond, C.I. 3843) x Vanguard	598	109	63	65
	532		691	125	71	85
	547		394	114	91	88
	557		552	119	72	87
	581		686	113	63	69
	611		509	110	77	82
	614		502	105	44	51
	615		594	111	65	66
	642		484	103	63	68
	643		456	113	72	84
	647		494	118	76	85
	651		630	106	64	66
	686		636	109	66	67
	712		659	121	87	94
	717		576	125	71	74
	735		689	112	63	67
	741		685	112	63	65
	744		544	107	65	64
	751		458	116	63	67
	754		567	126	72	84

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot	Plant ht. in inches per 3 row plot	Maturity date total per 3 row plot	Heading date total per 3 row plot
366	755	(D69-Bond, C.I. 3843) x Vanguard	663	110	65	67
	763		543	104	60	66
	773		587	107	62	66
	774		621	126	83	82
	785		616	131	91	104
	818		575	103	64	67
	843		598	106	66	66
	868		541	131	79	92
	875		464	112	59	67
	881		546	111	54	65
363	112	(D69-Bond, C.I. 3909) x Bond DCA, C.I. 3646	517	102	61	64
	162		581	108	64	59
	172		625	114	87	71
	176		597	109	75	79
	182		583	114	88	81
	185		399	102	70	61
	187		508	117	82	78
	227		580	107	78	63
	242		508	116	86	68
	263		678	116	77	68

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot	Plant ht. in inches per 3 row plot	Maturity date total per 3 row plot	Heading date total per 3 row plot
363	268	(D69-Bond, C.I. 3909) x Bond DCA, C.I. 3646	497	113	83	67
	335		566	114	76	79
	342		580	105	70	69
	377		606	109	72	69
	412		612	113	85	80
	424		657	120	74	75
	428		656	120	86	73
	444		613	115	70	67
	447		511	114	78	66
	468		552	105	81	69
	477		578	124	79	78
	484		445	116	82	67
	487		690	109	73	62
	488		521	105	65	66
	511		673	107	77	65
	528		603	111	72	65
	545		564	122	68	76
	554		597	118	66	76
	565		606	110	65	66
	571		563	122	86	75

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot	Plant ht. in inches per 3 row plot	Maturity date total per 3 row plot	Heading date total per 3 row plot
363	578	(D69-Bond, C.I. 3909) x Bond DCA, C.I. 3646	582	105	75	68
	585		506	109	79	68
	633		541	119	81	68
	644		499	99	76	63
	661		600	109	69	76
	664		587	110	75	76
	665		475	125	63	68
	752		510	100	72	57
	753		608	116	68	75
	758		546	118	75	78
	772		656	116	72	76
	827		513	111	79	79
	838		548	105	70	61
	842		552	105	76	64
	848		591	111	67	58
	854		520	107	63	60
	856		472	116	77	81
	867		585	118	68	77
	882		404	107	79	71
	888		566	108	64	58

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot	Plant ht. in inches per 3 row plot	Maturity date total per 3 row plot	Heading date total per 3 row plot
409	123	(D69-Bond, C.I. 3841) x Columbia	652	128	83	68
	147		550	123	83	79
	152		539	120	76	70
	156		645	129	76	82
	167		682	134	69	80
	211		610	134	82	83
	214		610	114	64	68
	218		502	115	72	78
	231		534	127	71	70
	244		538	127	84	82
	253		602	126	86	78
	257		495	121	70	72
	326		430	134	85	86
	345		547	118	61	67
	365		427	116	82	79
	368		566	121	74	70
	414		583	138	88	89
	426		603	130	99	99
	427		554	119	89	75
	432		471	117	65	68

Table I (continued).

Cross No.	Code No.	Cross	Yield grams per 3 row plot	Plant ht. in inches per 3 row plot	Maturity date total per 3 row plot	Heading date total per 3 row plot
409	435	(D69-Bond, C.I. 3841) x Columbia	481	122	74	80
	446		512	127	89	83
	456		539	133	76	79
	472		469	124	83	81
	478		600	127	92	88
	517		466	116	62	68
	544		628	129	75	71
	574		603	119	64	78
	628		565	122	67	77
	636		476	128	84	87
	637		554	124	64	72
	638		593	135	79	81
	657		577	118	87	66
	672		432	131	88	88
	677		586	118	72	70
	725		576	133	82	87
	726		502	133	89	88
	734		588	113	69	58
	738		549	124	67	79
	768		463	119	68	77

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot	Plant ht. in inches per 3 row plot	Maturity date total per 3 row plot	Heading date total per 3 row plot
409	781	(D69-Bond, C.I. 3841) x Columbia	703	119	67	78
	784		718	116	76	71
	786		628	115	60	71
	817		447	107	74	64
	823		403	106	56	63
	836		472	109	72	77
	845		532	122	82	85
	866		603	116	56	69
	874		512	112	70	61
	878		537	125	77	81
384	122	(Anthony-Bond, C.I. 3852) x Boone	543	112	81	83
	124		521	120	88	75
	128		555	113	92	90
	137		547	120	93	85
	213		614	138	90	94
	234		375	119	78	82
	237		507	111	100	107
	238		521	121	86	86
	254		525	121	80	86
	258		450	113	76	78

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot	Plant ht. in inches per 3 row plot	Maturity date total per 3 row plot	Heading date total per 3 row plot
384	272	(Anthony-Bond, C.I. 3852) x Boone	618	116	80	79
	315		635	122	93	72
	322		347	116	97	101
	324		593	116	85	83
	327		521	108	77	77
	333		466	109	100	93
	346		523	128	102	84
	357		474	129	90	88
	367		433	110	73	78
	383		529	127	100	86
	415		515	110	88	92
	437		375	116	97	93
	438		540	124	72	81
	441		491	123	103	81
	451		578	133	78	80
	461		540	130	75	77
	465		580	125	101	80
	476		428	122	88	83
	513		517	119	82	72
	524		465	124	75	76

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot	Plant ht. in inches per 3 row plot	Maturity date total per 3 row plot	Heading date total per 3 row plot
384	541	(Anthony-Bond, C.I. 3852) x Boone	482	121	106	82
	552		456	119	76	83
	572		653	117	96	87
	587		591	118	90	91
	627		563	130	88	87
	674		382	112	78	88
	711		492	111	89	76
	732		550	112	72	72
	733		355	125	90	91
	747		589	114	96	85
	766		526	114	87	76
	825		407	126	85	90
	831		649	112	89	81
	834		511	112	87	85
	861		486	120	90	79
	862		615	121	80	79
	863		410	127	75	78
	871		449	113	97	90
	876		440	115	81	91
	883		469	115	77	80

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot	Plant ht. in inches per 3 row plot	Maturity date total per 3 row plot	Heading date total per 3 row plot
358	154	Columbia x (D69-Bond, C.I. 3843)	654	129	77	73
	157		655	127	66	59
	164		495	137	81	85
	171		461	117	72	72
	173		648	135	69	78
	212		582	113	69	61
	226		625	124	74	78
	245		374	114	79	84
	246		687	132	75	79
	262		532	107	55	62
	313		614	124	57	66
	336		559	131	82	77
	343		603	117	69	60
	344		476	110	71	61
	352		657	143	82	84
	366		474	115	67	67
	372		631	141	75	81
	374		496	132	73	74
	375		514	124	75	75
	416		362	120	89	83

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot	Plant ht. in inches per 3 row plot	Maturity date total per 3 row plot	Heading date total per 3 row plot
358	417	Columbia x (D69-Bond, C.I. 3843)	484	136	78	75
	431		518	121	79	72
	464		596	142	69	74
	471		482	124	65	62
	482		526	116	57	62
	483		429	115	66	71
	486		459	121	71	69
	526		503	112	56	67
	533		664	136	82	85
	546		539	126	80	78
	561		662	127	77	74
	575		585	131	66	72
	616		528	121	79	82
	635		590	108	58	49
	656		571	122	73	78
	663		569	123	66	78
	668		465	109	63	65
	713		543	116	77	73
	715		584	126	63	67
	722		602	133	68	74

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot	Plant ht. in inches per 3 row plot	Maturity date total per 3 row plot	Heading date total per 3 row plot
358	728	Columbia x (D69-Bond, C.I. 3843)	589	121	78	83
	762		619	134	78	82
	765		610	121	64	64
	775		660	123	68	71
	777		521	125	69	68
	782		651	115	64	69
	815		533	130	62	70
	857		505	129	71	68
	872		509	126	80	70

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot: Orig.	Yield in grams per 3 row plot: Adj.	Plant height in inches per 3 row plot: Orig.	Plant height in inches per 3 row plot: Adj.	Maturity date total per 3 row plot: Orig.	Maturity date total per 3 row plot: Adj.	Heading date total per 3 row plot: Orig.	Heading date total per 3 row plot: Adj.	Percentage infection by *H. victoriae* per 3 row plot
375	111	Sac x Osage	276	519	94	110	54	71	66	68	120
	114		576		130		85		82		0
	116		429	490	113	117	81	85	89	90	30
	134		349	481	111	120	74	83	88	89	65
	136		669		126		75		82		0
	148		317	459	103	112	78	88	77	78	70
	151		646		113		72		73		0
	153		403	555	103	113	61	72	71	73	75
	178		485	495	108	109	50	51	54	54	5
	181		585		131		86		80		0
	228		613		130		81		79		0
	255		517	527	109	110	70	71	76	76	5
	261		515		115		64		62		0
	264		489	550	127	131	79	83	73	74	30
	267		243	476	104	119	63	80	68	70	115
	273		232	323	115	130	83	89	101	102	45
	276		570		103		69		65		0
	278		337	357	94	95	80	81	86	86	10
	285		475		99		65		66		0
	286		526		112		77		68		0

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot		Plant height in inches per 3 row plot		Maturity date total per 3 row plot		Heading date total per 3 row plot		Percentage infection by *H. victoriae* per 3 row plot
			Orig.	Adj.	Orig.	Adj.	Orig.	Adj.	Orig.	Adj.	
375	328	Sac x Osage	468		125		86		81		0
	334		602		120		69		69		0
	388		338	399	115	119	95	99	101	102	30
	425		599		109		68		73		0
	443		422	452	103	105	64	66	70	70	15
	463		507		131		87		81		0
	466		505		128		86		81		0
	515		397	478	113	118	78	84	87	88	40
	536		524		123		78		80		0
	577		572		99		76		72		0
	582		559		106		78		84		0
	583		563		115		82		66		0
	621		557		109		93		84		0
	645		378	418	98	101	62	65	64	64	20
	648		574		130		88		81		0
	652		545	555	128	129	78	79	69	69	5
	654		331	452	111	119	61	70	75	76	60
	667		596		106		75		77		0
	716		548		129		86		83		0
	745		613		119		64		70		0

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot: Orig.	Adj.	Plant height in inches per 3 row plot: Orig.	Adj.	Maturity date total per 3 row plot: Orig.	Adj.	Heading date total per 3 row plot: Orig.	Adj.	Percentage infection by *H. victoriae* per 3 row plot
375	783	Sac x Osage	530		114		96		91		0
	787		534		100		73		70		0
	788		382	443	116	120	71	75	68	69	30
	822		528		133		85		76		0
	844		536		132		86		82		0
	851		422	483	109	113	66	70	77	78	30
	853		597		128		87		82		0
	864		442		109		74		74		0
	865		336	387	115	118	63	67	82	83	25
	887		402	453	101	104	81	85	86	87	25
376	132	Osage x (Victoria x Hajira-Banner, C.I. 4021)	491	562	110	115	85	90	67	68	35
	143		599	609	124	125	80	81	56	56	5
	144		549	569	130	131	78	79	64	64	10
	161		284	466	103	115	66	79	78	80	90
	183		288	389	113	120	82	89	96	97	50
	188		443	453	112	113	93	94	100	100	5
	215		538	558	124	125	84	85	60	60	10
	216		299	441	108	117	79	89	83	84	70
	217		544	554	123	124	84	85	74	74	5
	224		261	473	86	100	47	62	54	56	105

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot: Orig.	Adj.	Plant height in inches per 3 row plot: Orig.	Adj.	Maturity date total per 3 row plot: Orig.	Adj.	Heading date total per 3 row plot: Orig.	Adj.	Percentage infection by *H. victoriae* per 3 row plot
376	235	Osage x (Victoria x	415	536	108	116	64	73	58	59	60
	248	Hajira-Banner, C.I.	368	439	121	126	83	88	89	90	35
	251	4021)	312	464	95	105	54	65	54	56	75
	284		285	447	108	119	63	75	81	83	80
	287		178	421	95	111	63	80	74	76	120
	321		554		123		87		82		0
	332		500	601	108	115	61	68	57	58	50
	356		378	449	112	117	67	72	73	74	35
	373		293	505	98	112	46	61	56	58	105
	376		248	400	103	113	82	93	89	91	75
	413		277	429	109	119	89	100	84	86	75
	434		451	502	115	118	97	101	89	90	25
	453		237	409	101	112	76	88	84	86	85
	457		241	342	115	122	74	81	96	97	50
	475		488	508	113	114	91	92	73	73	10
	512		530		125		83		86		0
	534		261	433	115	126	77	89	84	86	85
	551		319	481	100	111	52	64	67	69	80
	556		377	387	118	119	80	81	79	79	5
	562		188	390	103	116	59	73	82	84	100

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot: Orig.	Adj.	Plant height in inches per 3 row plot: Orig.	Adj.	Maturity date total per 3 row plot: Orig.	Adj.	Heading date total per 3 row plot: Orig.	Adj.	Percentage infection by *H. victoriae* per 3 row plot
376	612	Osage x (Victoria x	383	525	111	120	70	80	80	81	70
	623	Hajira-Banner, C.I.	243	435	111	124	70	84	77	79	95
	632	4021)	313	455	98	107	54	64	53	54	70
	653		419	490	114	119	83	88	84	85	35
	673		306	438	94	103	59	68	68	69	65
	685		505	525	124	125	84	85	62	62	10
	714		350	441	113	119	60	66	71	72	45
	742		447	528	119	124	72	78	80	81	40
	743		280	432	93	103	52	63	55	57	75
	748		506	557	111	114	75	79	64	65	25
	756		303	404	115	122	78	85	71	72	50
	761		263	415	111	121	76	87	80	82	75
	812		438		116		82		76		0
	813		154	538	92	117	35	99	48	52	190
	833		245	377	96	105	54	63	54	55	65
	835		248	471	99	114	58	74	75	77	110
	846		240	372	108	117	90	99	100	101	65
	847		251	342	106	112	67	73	80	81	45
	877		338	449	110	117	75	83	85	86	55
	884		398	449	108	111	65	69	57	58	25

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot: Orig.	Adj.	Plant height in inches per 3 row plot: Orig.	Adj.	Maturity date total per 3 row plot: Orig.	Adj.	Heading date total per 3 row plot: Orig.	Adj.	Percentage infection by *H. victoriae* per 3 row plot
377	115	(Victoria x Hajira-	306	498	96	109	55	69	72	74	95
	118	Banner, C.I. 4022)	225	397	103	124	79	91	93	95	85
	138	x Osage	273	556	87	106	45	65	44	47	140
	145		528	538	112	113	69	70	64	64	5
	158		320	441	111	119	82	91	93	94	60
	174		389	409	108	110	82	84	82	82	15
	221		282	464	100	112	67	80	66	68	90
	222		240	554	106	127	59	81	76	79	155
	223		372	584	93	107	60	75	60	62	105
	236		441	471	119	121	74	76	84	84	15
	271		352	484	109	118	72	81	73	74	65
	275		295	386	104	110	81	87	88	89	45
	282		278	410	99	108	74	83	83	84	65
	317		384	495	106	113	95	103	77	78	55
	331		126	510	99	124	62	89	86	90	190
	361		619		109		62		62		0
	385		308	399	100	106	72	78	86	87	45
	433		239	401	109	120	67	79	80	82	80
	436		554		121		89		89		0
	445		544	554	101	102	75	76	61	61	5

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot: Orig.	Adj.	Plant height in inches per 3 row plot: Orig.	Adj.	Maturity date total per 3 row plot: Orig.	Adj.	Heading date total per 3 row plot: Orig.	Adj.	Percentage infection by *H. victoriae* per 3 row plot
377	452	(Victoria x Hajira-	285	406	102	110	59	68	70	71	60
	455	Banner, C.I. 4022)	205	438	94	109	64	81	74	76	115
	473	x Osage	237	470	101	116	57	74	69	71	115
	481		235	437	104	117	61	75	84	86	100
	514		551	571	101	102	60	61	61	61	10
	516		255	397	89	98	77	87	88	89	70
	538		235	397	91	102	76	88	88	90	80
	564		203	405	84	97	75	89	89	91	100
	566		319	521	102	115	60	74	77	79	100
	568		217	470	102	119	59	77	78	81	125
	573		227	541	94	115	52	74	63	66	155
	576		266	398	113	122	81	90	91	92	65
	584		294	355	105	109	78	82	90	91	30
	617		167	501	118	140	63	87	85	88	165
	625		210	513	98	118	56	78	69	72	150
	626		278	511	95	110	68	85	81	83	115
	641		213	537	100	121	54	77	67	70	160
	655		383	464	108	113	83	89	89	90	40
	662		398	519	104	112	67	76	75	76	60
	671		211	454	88	104	76	93	88	90	120

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot: Orig.	Adj.	Plant height in inches per 3 row plot: Orig.	Adj.	Maturity date total per 3 row plot: Orig.	Adj.	Heading date total per 3 row plot: Orig.	Adj.	Percentage infection by *H. victoriae* per 3 row plot
377	731	(Victoria x Hajira-	255	447	88	101	79	93	84	86	95
	771	Banner, C.I. 4022)	391	462	110	115	78	83	88	89	35
	776	x Osage	317	509	101	114	73	87	84	86	95
	811		199	391	108	121	84	98	97	99	95
	816		246	519	97	115	58	77	64	67	135
	821		461	501	102	105	69	72	60	60	20
	826		375	476	103	110	69	76	82	83	50
	832		329	461	112	121	59	68	79	80	65
	852		400	471	111	116	62	67	79	80	35
	858		338	459	97	105	72	81	82	83	60
381	113	(Victoria x Hajira-	424	444	129	130	76	77	81	81	10
	125	Banner, C.I. 4020) x	538		125		65		75		0
	131	D69-Bond, Sel. 2042-8	232	434	109	122	65	79	84	86	100
	135		533		132		62		73		0
	146		456		136		82		90		0
	166		532		134		80		90		0
	175		660		120		79		73		0
	177		502		126		69		76		0
	184		659	689	124	126	76	78	83	83	15
	186		517		131		65		74		0

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot: Orig.	Adj.	Plant height in inches per 3 row plot: Orig.	Adj.	Maturity date total per 3 row plot: Orig.	Adj.	Heading date total per 3 row plot: Orig.	Adj.	Percentage infection by *H. victoriae* per 3 row plot
381	233	(Victoria x Hajira-	497	517	134	135	72	73	79	79	10
	241	Banner, C.I. 4020) x	489		135		66		76		0
	247	D69-Bond, Sel. 2042-8	141	455	106	121	59	81	86	89	155
	266		516	546	136	138	69	71	81	81	15
	274		629		136		79		84		0
	283		566		113		60		68		0
	288		579		119		72		76		0
	316		484		131		70		75		0
	337		444		128		68		77		0
	341		529		142		69		76		0
	348		507		125		97		99		0
	354		482		134		73		79		0
	358		518		132		72		76		0
	371		487		138		73		77		0
	421		436		123		71		78		0
	422		460		132		71		75		0
	423		526		136		67		77		0
	485		347	418	111	116	72	77	89	90	35
	522		256	458	119	132	55	69	81	83	100
	531		450		134		74		80		0

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot: Orig.	Yield in grams per 3 row plot: Adj.	Plant height in inches per 3 row plot: Orig.	Plant height in inches per 3 row plot: Adj.	Maturity date total per 3 row plot: Orig.	Maturity date total per 3 row plot: Adj.	Heading date total per 3 row plot: Orig.	Heading date total per 3 row plot: Adj.	Percentage infection by *H. victoriae* per 3 row plot
381	542	(Victoria x Hajira-	404		131		70		77		0
	543	Banner, C.I. 4020) x	658		131		79		83		0
	553	D69-Bond, Sel.2042-8	280	462	117	129	60	69	66	68	90
	558		517		130		65		75		0
	588		567		135		83		83		0
	613		517		134		72		74		0
	618		575		131		68		76		0
	646		694		138		95		96		0
	666		579		130		65		75		0
	675		477		130		65		74		0
	676		486		129		71		74		0
	678		544		130		70		75		0
	683		545		121		70		68		0
	684		609		115		82		83		0
	724		550		114		70		65		0
	736		484		139		68		76		0
	746		598		137		67		73		0
	764		335	345	132	133	76	77	80	80	5
	767		545		131		64		73		0
	873		530		129		66		74		0

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot: Orig.	Adj.	Plant height in inches per 3 row plot: Orig.	Adj.	Maturity date total per 3 row plot: Orig.	Adj.	Heading date total per 3 row plot: Orig.	Adj.	Percentage infection by *H. victoriae* per 3 row plot
386	117	(Victoria x Hajira-	326	468	102	111	63	73	68	69	70
	121	Banner, C.I. 4021)	387	498	107	114	57	65	68	69	55
	126	x Vikota	644		114		80		83		0
	127		556		104		66		67		0
	133		548		114		78		82		0
	142		555		102		67		67		0
	155		658		124		82		80		0
	165		707		118		89		88		0
	243		242	414	103	114	68	80	85	87	85
	252		683		119		69		74		0
	277		255	417	120	131	67	79	84	86	80
	314		550		128		95		94		0
	318		436	507	114	119	61	66	77	78	35
	325		626		117		71		84		0
	351		383	504	108	116	60	69	65	66	60
	353		346	467	108	116	62	71	72	73	60
	381		680		122		76		85		0
	382		260	493	112	127	77	94	82	84	115
	386		316	458	106	115	79	89	86	87	70
	418		194	387	99	112	60	74	73	75	95

Table I (continued).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot Orig.	Yield in grams per 3 row plot Adj.	Plant height in inches per 3 row plot Orig.	Plant height in inches per 3 row plot Adj.	Maturity date total per 3 row plot Orig.	Maturity date total per 3 row plot Adj.	Heading date total per 3 row plot Orig.	Heading date total per 3 row plot Adj.	Percentage infection by *H. victoriae* per 3 row plot
386	442	(Victoria x Hajira-Banner, C.I. 4021) x Vikota	454		121		83		84		0
	448		701		119		97		90		0
	458		711		121		85		90		0
	462		513		107		60		74		0
	521		621		106		75		71		0
	523		360	492	105	114	56	65	78	79	65
	525		602		119		67		81		0
	535		460	500	123	126	73	76	82	82	20
	555		586		113		69		73		0
	563		567		126		77		86		0
	567		536		118		69		83		0
	586		627	637	116	117	81	82	82	82	5
	622		519	539	117	118	81	82	77	77	10
	624		565		109		59		65		0
	634		516		112		70		71		0
	658		568		117		78		89		0
	681		684		133		74		83		0
	682		667		129		84		91		0
	688		662		117		71		84		0
	718		439		115		81		89		0

Table I (concluded).

Cross No.	Code No.	Cross	Yield in grams per 3 row plot: Orig.	Adj.	Plant height in inches per 3 row plot: Orig.	Adj.	Maturity date total per 3 row plot: Orig.	Adj.	Heading date total per 3 row plot: Orig.	Adj.	Percentage infection by *H. victoriae* per 3 row plot
386	721	(Victoria x Hajira-	636		129		79		88		0
	723	Banner, C. I. 4021)	677		119		85		86		0
	727	x Vikota	302	403	106	113	82	89	80	81	50
	737		638		122		75		85		0
	778		591		119		65		76		0
	814		363	403	109	112	72	75	83	83	20
	824		350	411	114	118	81	85	77	78	30
	828		482		109		82		92		0
	855		352	625	99	117	47	66	63	66	135
	886		587		117		78		92		0
101	265	Bulk of Cross No. 358	488		127		74		69		0
102	347	" " 363	634		123		77		71		0
103	837	" " 375	599		125		87		67		0
104	548	" " 409	705		124		83		62		0
105	256	" " 381	574		130		86		74		0
106	885	" " 366	579		117		76		63		0
107	631	" " 376	463	554	112	118	77	83	63	64	45
108	757	" " 377	397	488	111	118	81	88	74	75	50
109	841	" " 386	553	563	124	125	81	82	73	73	5
110	362	" " 384	645		121		101		78		0
111	537	Clinton	556		111		66		77		0
112	687	Benton	569		128		70		77		0